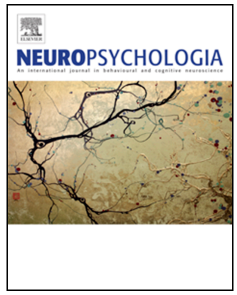

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PII: S0028-3932(19)30331-8

DOI: https://doi.org/10.1016/j.neuropsychologia.2019.107290

Reference: NSY 107290

To appear in: *Neuropsychologia*

Received Date: 6 August 2019

Revised Date: 3 November 2019

Accepted Date: 29 November 2019

The behavioral and neural basis of foreign language effect on risk-taking

Liling Zheng[1], Dean Mobbs[2], Rongjun Yu[3]

[1]Guangdong Key Laboratory of Mental Health and Cognitive Science, Center for Studies of Psychological Application, School of Psychology, South China Normal University, Guangzhou, China

[2] Department of Humanities and Social Sciences and Computation and [4]Neural Systems Program at the California Institute of Technology, 1200 E California Blvd, HSS 228–77, Pasadena, California 91125, USA.

[3] Department of Psychology, National University of Singapore, Singapore

Address correspondences to:

*Rongjun Yu, Department of Psychology, National University of Singapore, Block AS4, #02-17, 9 Arts Link, Singapore, 117570, Email: psyyr@nus.edu.sg

Abstract:

Recent studies show that people exhibit a reduced decision bias in a foreign language relative to their native language. However, the underlying mechanism remains unknown. Using functional magnetic resonance imaging (fMRI) combined with an even-probability gambling task in which gambling feedback was presented in either a native language or a foreign language after each decision, we assessed the neural correlates of language modulated behavioral changes in decision making. In both foreign and native language contexts, participants showed a behavioral pattern resembles the Gambler's fallacy that losing a gamble leads to more betting than winning a gamble. While there was no language difference in gambling, bilateral caudate and amygdala gain signals were exaggerated by foreign language in relative to native language, suggesting that foreign language enhanced neural responses to rewards. Moreover, the individual difference in foreign language-induced Gambler's fallacy-like decision bias was associated with activation in the right amygdala and ventromedial prefrontal cortex, as well as functional connectivity between right amygdala and right putamen/right posterior insula. Our results confirm that outcome processing in emotion-related regions may underlie individual differences in foreign language effects in judgment and decision making.

Keywords: bilingualism; foreign language; decision making; functional magnetic resonance imaging (fMRI); emotion

1. Introduction

Approximately half of the world's population are bilingual or multilingual (Bialystok et al., 2012; François Grosjean, 2010; Marian and Shook, 2012). In the US, over 20% of the population speak a foreign language at home other than English[1]. These individuals often occupy careers where accurate decision making is vital, including financial, medical, education, and politics vocations. Recently, researchers have proposed that using a foreign language to present information can reduce decision bias such as framing effect, loss aversion and hot hand fallacy (Costa et al., 2014a; Gao et al., 2015; Keysar et al., 2012), known as the Foreign Language Effect (for reviews see Costa, Vives, & Corey, 2017 and Hayakawa, Costa, Foucart, & Keysar, 2016). Its impact is also evident in the context of moral judgments and choices (Corey et al., 2017; Costa et al., 2014b; Geipel et al., 2016, 2015a; Hayakawa et al., 2017; Muda et al., 2018). On the whole, it seems like the use of a foreign language makes people more coolly objective than in their native tongue when making decisions and judgments. Here we investigate whether and how using a foreign language to present information influence people's risk decision-making processes.

1.1 Theories of foreign language effect

Emotion-reducing hypothesis

Most of the work on foreign language effect interpreted their findings from a reduction in emotional responses (Costa, Foucart, Arnon, et al., 2014; Costa, Foucart, Hayakawa, et al., 2014; Hayakawa et al., 2017; Keysar et al., 2012). This hypothesis builds on evidence that messages processed in a foreign language usually elicit a milder emotional response than those processed in a native tongue (Dewaele, 2004; Harris, 2004; Harris, Ayçiçeği, & Gleason, 2003; Hsu, Jacobs, & Conrad, 2015; Iacozza, Costa, & Duñabeitia, 2017; for a review see Pavlenko, 2012). The emotional

[1] U. S. Census Bureau (2018) 2013-2017 American Community Survey 5-Year Estimates. Language Spoken at Home, Table S1601. Retrieved from https://factfinder.census.gov/bkmk/table/1.0/en/ACS/17_5YR/S1601

distance triggered by a foreign language is believed to weaken the fast, heuristic decision making and promote more analytical thinking, thus to reduce decision biases (Costa et al., 2014a; Keysar et al., 2012). The absence of foreign language effect in emotion neutral tasks, such as cognitive reflection task (Costa et al., 2014a) and the Moses illusion task (Geipel et al., 2015a) added evidence to the emotion-reducing view of foreign language effect.

Positive bias hypothesis

However, several studies have shown that emotional distance in a foreign language may be restricted to negative words and is not the case for positive words (Conrad et al., 2011; Sheikh and Titone, 2016; Wu and Thierry, 2012). For example, reading a positive or neutral word in a foreign tongue activates its native language equivalent, whereas reading a negative word does not (Wu and Thierry, 2012). It may be that a foreign language is usually learned and used through social interactions that are often pleasant (Caldwell-Harris, 2015; Sheikh and Titone, 2016). For example, endorsement expressed in English elicited larger SCRs than in Mandarin for Chinese-English bilinguals (Caldwell-Harris et al., 2011). Besides, research on human judgment of risks and benefits demonstrated that using a foreign language promoted overall positive affect and reduced risk perception (Hadjichristidis et al., 2015). Taken together, using a foreign language may produce a positivity bias.

1.2. The Gambler's fallacy

People learn from experience and modulate their choices according to previous decision outcomes. Individuals tend to take more risks after losses than after wins (Ayton and Fischer, 2004; Brevers et al., 2017, 2017; Campbell-Meiklejohn et al., 2008; Dong et al., 2014; Losecaat Vermeer et al., 2014; Tversky and Kahneman, 2016; Xue et al., 2011), a pattern resembling the Gambler's fallacy (GF). GF refers to a misconception that a certain random event is less likely to happen after a series of the same event. It should be noted that the pattern of increased risk-taking following losses and decreased risk-taking following wins is known as “loss chasing” (Brevers et al., 2017; Campbell-Meiklejohn et al., 2008). However, considering that continued risk taking after losses has a similar pattern to the GF and arises from the GF cognitive bias (Dong et al., 2014; Xue et al., 2011), in this study, we termed this behavioral tendency as the “GF-like behavior” (Xue et al., 2011).

Unlike most of the decision biases, which are supported by the emotional and intuitive system (Stanovich et al., 2000; Tversky and Kahneman, 1974), GF or GF-like behavioral patterns (e.g., the tendency to take more risks after losses than after wins) are believed to be associated with strong cognitive control ability and weak affective decision-making (Huang et al., 2019; Xue et al., 2012b, 2012a, 2011). For instance, individuals with stronger affective decision-making capacity, as measured by the Iowa gambling task (IGT), showed less GF, while those with stronger cognitive control ability, as reflected by higher working memory capacity, showed more GF (Huang et al., 2019; Xue et al., 2012a).

1.3. Study aims and predictions

Here, we used functional magnetic resonance imaging (fMRI) to explore the neural basis of foreign language effect on risky decision-making, using a gambling task that induces the GF-like behavioral pattern (Gao et al., 2015). Participants were asked to choose to play or leave (not play) gambles with a 50% chance of winning. The feedback was presented immediately after each choice in either a native tongue or a foreign language. Emotionally charged words, such as “great” or “damn”, were used to elicit emotional reactions to these words. The feedback words are simple, high-frequency, and easy to understand. This minimizes the potential confounds of complex language materials, e.g., heightened cognitive load and the anxiety caused by processing foreign language (Chan et al., 2016; van Hugten and van Witteloostuijn, 2018).

According to the emotion-reducing hypothesis, lower activations in emotion-related brain areas should be observed in the foreign language context. Specifically, in the foreign language condition, neural regions implicated in reward processing, such as ventral striatum (Schultz et al., 1997) and ventral medial prefrontal cortex (vmPFC, Winecoff et al., 2013) should be less activated when processing positive feedback. Similarly, brain areas involved in processing losses, like anterior insula (Samanez-Larkin et al., 2008) should be less activated when processing negative feedback. This neural pattern will be associated with more GF-like biases due to weakened affective decision-making. However, if the positive bias hypothesis is the case, we should observe higher brain sensitivity to positive feedback in reward processing brain regions in the foreign language context, and this may correspond to more gambling options, given that positive affective state is often associated with more positive expectations, reduced risk perception and less risk aversion (George and Dane, 2016; Moore and Chater, 1999).

2. Materials and methods

2.1. Participants. Thirty-two Chinese-English bilinguals (15 females, 20.4 ± 2.25 years) participated in the present experiment. They were paid for their participation. All participants were right-handed. They had a normal or corrected-to-normal vision and were free of neurological diseases. Participants began to learn English at approximately age 8 (SD = 2.4), and had no experience of studying abroad. All the participants were Chinese-dominant bilinguals. They rated their own English reading proficiency on average at 5.57 (SD = 1.29); and their Chinese reading proficiency on average at 8.60 (SD = 0.87) (on a scale of 1, not literate, to 10, very literate). This study was approved by the local Ethics Committee. All participants gave written informed consent before participating in the experiments. Data from two participants were not included in statistical analyses because of excessive movement artifact (> 3 mm in translation and framewise displacement (FD) of more than 10% of the volumes > 0.5° in rotation). One more participant was also excluded due to poor performance on catch trials, i.e., the averaged proportion of choosing “play” on catch trials was lower than 80%.

2.2. Stimuli. In accordance with a previous study (Gao et al., 2015), there were five potential gain values (+100, +80, +60, +40, and +20) and five potential loss values (-50, -40, -30, -20, and -10). Each gain value was paired with one loss value so that there were twenty-five possible risky bets. It is believed that this range of gambles could elicit a wide range of risk attitudes (Tom et al., 2007). As people are more sensitive to losses than to equivalent gains, the subjective impact of losses is roughly twice that of gains (Abdellaoui et al., 2007; Tom et al., 2007; Tversky and Kahneman, 1992). Therefore, the loss magnitude should be doubled when calculating the expected value (EV) for losses. Finally, for the 25 risky bets, there were 5 bets with EV of 0, 4 with EV of 20 (-20), 3 with EV of 40 (-40), 2 with EV of 60 (-60), and 1 with EV of 80 (-80).

In addition, each of the five gain values was paired with zero losses to produce five safe bets, e.g. 50% chance of winning ¥80 and 50% chance of losing nothing. Participants should always choose to play in these catch trials. Five catch trials were presented twice in each language condition. Participants who chose "play" less than 8 trials in each language condition were excluded from further analysis. These catch trials were not included in the following statistical analysis. Every gamble consisted of a sign and a number representing the potential gain or loss displayed to the left or right of a horizontal bar symbolizing a 50/50 chance of either winning or losing (Figure. 1).

The feedback words used were ten English words and ten Chinese words, see Table 1. The English words were adjectives with high homogenous lexical frequency (Coltheart, 1981). The mean affective valence (positive = 7.44, negative = 3.31; $p < 0.001$) and arousal (positive = 4.19, negative = 4.49; $p > 0.1$, Warriner, Kuperman, & Brysbaert, 2013) was controlled. The Chinese words were the best translation equivalents of these English words. Thirty college students (15 females, 20.23 ± 1.55 years) from local community were recruited to rate the words. They were Chinese-dominant bilinguals and began to learn English at about age 8.00 (SD = 0.87). They had no experience of studying abroad. The result showed no statistically reliable differences between languages on measures of valence, arousal, or familiarity.

2.3. Procedure. Before taking part in the formal experiment, participants completed a lexical test. Only those who correctly translated all the English words into Chinese participated in the subsequent fMRI scanning. Then, eight practice trials were given to ensure they were familiarized with the task prior to fMRI scanning. All instructions and stimuli were presented using E-prime 2.0 on a Dell laptop and were viewed by participants through a mirror mounted on the head coil in the MRI scanner. Participants put their fingers on the numerical response box, i.e., left thumb on “2”, right thumb on “3”. In addition to a base payment (￥50, about \$ 7.5), participants were told that 40% of the gambles they chose to play would be randomly selected to calculate their final reward. Every ten points accumulated equated to one RMB yuan (about 15 cents).

In the scanner, participants were presented with two sessions of 110 trials. For one of the sessions, the feedback was given in Chinese and the other was given in English. Session order was randomized and counterbalanced across participants. In each session, the 25 risky bets were presented four times in a pseudorandomized order together with five safe bets, each appearing twice.

During each trial, a fixation point “+” was presented for a random duration between 1 s and 5 s followed by a risky bet. The gamble options “play” and “leave” were randomly presented on two sides of the horizontal bar. Participants were asked to indicate whether they wanted to play or not each bet by pressing one of the response keys (“2” for the left-side option, “3” for the right-side option) within 4 s. The selected option was highlighted for the rest of 4 s. If the choice was “play”, the feedback was provided for 2 s in the form of a printed word followed by the corresponding numerical outcome, displayed for 1 s. If the choice was “leave”, the feedback was the words “leave” or the equivalent words in Chinese and the numerical outcome was zero. If no response was made within the allotted time, the words “Time’s up” or the equivalent phrase in Chinese was displayed for 1 s.

2.4. Data collection. All images were acquired using a 3T MRI scanner (Siemens

Medical Solutions, Erlangen, Germany). Participants' heads were secured to minimize movement using a 12-channel head-coil system. Functional scans were obtained using a single shot T2*-weighted gradient echo-planar imaging (EPI) sequence. The following scan parameters were used: 33 oblique axial slices, 3 mm-thickness; TR = 2000 ms; TE = 30 ms; flip angle = 90°; FOV = 224 mm ; voxel size = 3 × 3 × 3 mm. T1 weighted structural images were acquired at a resolution of 1 × 1 × 1 mm.

2.5. Behavioral data analysis. Binary logistic regression was performed on play-or-leave choices, with play or leave decisions for each gamble as the dependent variable. The predictors included the language of feedback (using Chinese as referent), the size of potential gain, the size of potential loss, and two dummy variables representing the preceding feedback valence (using neutral feedback as referent). Two regressors representing the interaction between language and preceding feedback valence were also included. Reaction times were examined with equivalent standard regression analysis. Participants were modeled with random effects. β-value are reported with their standard errors (SEs).

2.6. Imaging data analysis. Neuroimage data were preprocessed and analyzed using SPM8 (http://www.fil.ion.ucl.ac.uk/spm/). The first four volumes were discarded to allow the MR signal to reach steady-state equilibrium. EPI images were since interpolated in time to correct for slice-timing differences and realigned to the first scan by rigid-body transformation to correct for head movements. Utilizing linear and nonlinear transformation, and smoothing with a Gaussian kernel of full-width-half maximum 6 mm, EPI and structural images were coregistered to the T1 MNI 152 template (Montreal Neurological International Consortium for Brain Mapping). Global changes were removed by high-pass temporal filtering with a cutoff of 128 s to remove low-frequency drifts in the signal.

At the first-level analyses, the general linear model (GLM) was performed on the native and foreign language sessions separately for each subject. The GLM included four regressors of interest representing the gamble option presentation (Onset is at the beginning of each gamble option presentation, duration = 0.) and the three feedback conditions, i.e., positive, negative, and neutral feedback (Onset is at the beginning of each feedback word presentation, duration = 0.). The gamble option presentation regressor had three parametric modulators, i.e., the size of potential gain, the size of potential loss, and the preceding outcome. Six regressors were also included to account for residual motion-related signal changes after volume registration. Multiple linear regression was then run to generate parameter estimates for each regressor at every voxel. To examine the language effect, the contrast images of interest (i.e., positive versus (vs.) negative feedback; negative vs. positive feedback), from two languages were entered into paired-samples t-test for the second-level group analysis. Considering the potential effect of language proficiency, we included the self-rating foreign language (i.e., English) proficiency as a covariate in the group-level analysis.

We next investigated whether individual differences in feedback-related brain activity were related to individual differences in the use of GF-like strategy between languages. We extracted beta values representing the cross-language difference in risk-taking behavior after negative vs. positive feedback (Chinese (negative vs. positive) vs. English (negative vs. positive) for each participant from the logistic regression model (behavioral d-GF). We conducted a whole-brain regression analysis on language effect using the behavioral d-GF as a covariate. Data from one participant were excluded from this analysis due to extreme behavioral d-GF value.

In addition to conducting a whole-brain regression analysis, we further examined the feedback-dependent functional connectivity in each language and made a comparison between languages. Given that we found amygdala activation in the comparison between two languages, and we found a relationship between behavioral d-GF and the language effect at the right amygdala, we investigated feedback-dependent functional connectivity of the right amygdala with other regions using the PsychoPhysiological Interaction (PPI) (Friston et al., 1997; O'Reilly et al., 2012). We first created a seed region using a 3-mm diameter sphere in the right amygdala [21, -6, -12] activated in positive vs. negative feedback contrast. At the first-level analysis, we applied a standard context-dependent PPI (Gitelman et al., 2003) as follows. First, we extracted the first mean time series within the right amygdala seed. We then created psychophysiological interaction term (PPI regressor) using element-by-element products of the extracted, deconvolved amygdala time series and a vector coding for the main effect of feedback valence (1 for positive feedback, -1 for negative feedback). This product was then reconvolved with the canonical hemodynamic response function (HRF) and entered as PPI regressor along with the feedback valence (psychological), right amygdala time series (physiological), and the head-motion (nuisance) regressors. Subject-specific PPI models were run, and contrast images were generated for positive and negative PPIs. Correlation between cross-language difference in feedback-depended functional connectivity and the behavioral d-GF was assessed in the whole-brain regression analysis with ranked overall behavior d-GF as a covariate.

We reported only those clusters that survive cluster-level correction for multiple comparison (family-wise error, FWE; $p < 0.05$) over the whole brain and activations survived $p < 0.05$ FWE after small volume correction (svc) over priori regions of interest (ROIs), namely positive and negative outcome related regions: the ventral striatum (O'Doherty, 2004; 6mm sphere at ± 14, 10, and -10), the vmPFC (Winecoff et al., 2013; 10 mm sphere at ± 6, 34 and -16); the dorsal striatum (i.e., caudate, putamen), amygdala, and anterior/posterior insula defined by the corresponding automated anatomical labeling masks (Tzourio-Mazoyer et al., 2002). Because we found significant language effect in amygdala, for the PPI analysis, we defined striatum and insula as ROIs, considering their roles in emotion processing/affective decision making (Badgaiyan, 2010; Gu et al., 2013) and the important functional interactions between them and amygdala (Moraga-Amaro and Stehberg, 2012; Peters et al., 2013).The cluster forming threshold is at $p < 0.005$. For display purposes, all images are depicted at $p < 0.005$.

3. Results

3.1. Behavioral results

Participants tended to play more gambles as the size of potential gain increased (β = 1.68 (0.05), $p < 0.001$). In contrast, they played fewer gambles as the size of potential loss increased (β = -1.68 (0.05), $p < 0.001$). Compared with neutral feedback, positive feedback decreased participants' risk taking behavior (β = -0.28 (0.14), $p < 0.05$). Negative feedback had little impact (β = 0.05 (0.13), $p > 0.05$). No significant difference was found between languages, nor a significant interaction involving language, all $ps > 0.05$.

In order to get more information from the data, logistic regression model with four regressors (i.e., the size of potential gain, the size of potential loss, and two dummy variables representing feedback valence (using neutral as referent) was performed for Chinese and English conditions separately on play-or-leave choices. In both language conditions, participants tended to play more gambles as the size of the potential gain increased (Chinese, β = 1.77 (0.08); English, β = 1.63 (0.07), $ps < 0.001$) and played fewer gambles as the size of potential loss increased (Chinese, β = -1.71 (0.08); English, β = -1.70 (0.07), $ps < 0.001$). Compared with neutral feedback, positive feedback decreased risk-taking behavior in Chinese context (β = -0.32 (0.14), $p < 0.05$), but did not affect risk taking in English context (β = 0.08 (0.13), $p > 0.05$); while negative feedback increased risk-taking behavior in English context (β = 0.28 (0.13), $p < 0.05$), but did not affect the risk taking in Chinese context (β = 0.02 (0.14), $p > 0.05$).

Participants spent less time making decisions as the size of potential gain increased (β = -64.74 (5.34), $p < 0.001$), but took more time as the size of potential loss increased (β = 61.01 (5.48), $p < 0.001$). Participants were overall slower making their decisions in English relative to in Chinese context, β = 80.37 (19.25), $p < 0.001$. Compared with neutral feedback, participants' responses following positive feedback (β = 16.21 (19.10), $p > 0.05$) or negative feedback (β = -1.87 (18.44), $p > 0.05$) were neither fast nor slow. There were no significant interactions between language and feedback valence on reaction times, $ps > 0.05$. Finally, we investigated the potential effect of self-rated foreign language proficiency by conducting regressions separately for play-or-leave choices and reactions times after adding the interaction between language (using Chinese as referent) and English reading proficiency as a regressor. English proficiency did not impact the proportionated risky choices (β = 0.05 (0.06); $p >$ 0.05) and reaction times (β = 4.23 (8.23); $p >$ 0.05) between languages.

3.2. Neuroimaging results

For both languages, positive feedback vs. negative feedback elicited widespread activations in the dopaminergic reward system including the striatal networks (i.e. ventral striatum, caudate, putamen), vmPFC, anterior cingulate cortex, and amygdala as shown in Table 2, consistent with their roles in processing gains (Haber and Knutson, 2010; Murray, 2007). Direct comparison of positive vs. negative feedback contrast between languages revealed significant higher activations in bilateral caudate (left, x = -15, y = 21, z = 9; t = 6.42, p < 0.001, FWE svc; right, x = 12, y = 18, z = 12; t = 4.46, p < 0.05, FWE svc) and bilateral amygdala (left, x = -21, y = -6, z = -12; t = 3.83, p < 0.05, FWE svc; right, x = 21, y = -6, z = -12; t = 4.61, p < 0.01, FWE svc) in English context than in Chinese context, see Figure 2.A. Negative feedback minus positive feedback elicited no significant brain activations in both languages. Including the English proficiency as a covariate didn't change the main findings.

We used behavioral d-GF as a covariate to modulate the effect based on cross-language difference (English-Chinese) in the positive vs. negative feedback contrast. People who were less likely to fall into the GF-like bias in English context had stronger activity in right amygdala (x = 30, y = -3, z = -15; t = 4.07, p < 0.001, FWE svc) and bilateral vmPFC (left, x = -3, y = 42, z = -12; t = 4.38, p < 0.05, FWE svc; right, x = 3, y = 39, z = -15; t = 5.56, p < 0.001, FWE svc) in response to previous positive vs. negative feedback, see Figure 2.B. No other significant brain activations were found in regression analysis.

Using cross-language difference (English-Chinese) in positive vs. negative feedback contrast with the right amygdala as a seed and ranked behavioral d-GF as a covariate. We found enhanced activations in right putamen (x = 27, y = 18, z = 3; t = 4.04, p < 0.05, FWE svc) and right posterior insula (x = 45, y = -3, z = 3; t = 4.13, p <

0.05, FWE svc) in foreign language condition, as shown in Figure 2.C. That is, those who had stronger feedback-dependent functional connectivity strength between right amygdala and right putamen/right posterior insula in foreign language context were less likely to fall into the GF-like bias.

4. Discussion

Using an even-probability gambling task that manipulates gambling feedback on a trial-by-trial basis, the present study investigated how language modulates feedback-related brain activities and the subsequent risk-taking behaviors. Overall, participants showed a behavioral pattern resembling the GF that they were more likely to take a risk after losing a gamble than after winning a gamble. Although there was no language effect on GF-like behavior, compared with using a native language, positive vs. negative feedback provided in foreign language lead to higher activation in bilateral caudate and bilateral amygdala. Moreover, regression analysis showed that participants with higher activations in the right amygdala and bilateral vmPFC, as well as stronger feedback-dependent functional connectivity between right amygdala and right putamen/right posterior insula in the foreign language compared with the native language condition, tended to use less GF-like strategies in the foreign than in the native language. These findings demonstrated a modulation effect of language on neural responses to gambling feedback and its influence on subsequent risk-taking behaviors, providing novel evidence on the neural substrates of foreign language effect on risky decision making.

Our subjects showed a strong GF-like behavioral pattern in a simple gambling task offering even probabilities of winning and losing, as they bet significantly more after losing a gamble than after winning a gamble, even though wins and losses were governed purely by chance. However, a previous study (Gao et al., 2015) using the same paradigm found an opposite behavioral pattern that participants were more likely to take a risk after wins than after losses. This behavioral pattern resembles the hot hand fallacy (HHF), which can be regarded as the counterpart to the GF. In the HHF, people tend to predict the same outcome as the previous event, known as the positive recency, while in the GF, people predict the opposite outcome of the previous event - negative recency (Ayton and Fischer, 2004). The GF pattern in our study was in conflict with the previous study showing HHF in the native language condition (Gao et al., 2015). We suspect that the discrepancy of results may derive from the culture differences between the two groups of samples. Subjects were native speakers of Chinese in both studies. However, our subjects were recruited from the local community in China and had few chances to experience western cultures; while Gao et al.'s subjects were recruited from the western community and had been exposed to English for more than decades on average. It is proposed that cultural values and beliefs play important roles in gambling behavior (see Raylu and Oei, 2004, for a review). Research exploring the cultural difference in gambling fallacies found that Asians (mainly Chinese) are more subject to the GF and less subject to the HHF than Euro-Canadians due to their different theories about change (Ji et al., 2015). Accordingly, we suspect that successful acculturation might be a potential reason to explain Gao et al.'s subjects' higher preference for HHF than our subjects.

Another difference between our study and Gao et al.'s research is that they found HHF only in the native language, whereas we found GF in both native and foreign languages, suggesting that a foreign language reduced the HHF but not the GF. Greater GF-like behavior is predicted by emotional attenuation and greater cognitive control because the decision maker needs to override the default inclination to avoid the prepotent win-stay, loss-switch response (Xue et al., 2012b). The HHF, on the other hand, may result from adherence to these (presumably emotionally-mediated) default inclinations. These results suggest that the foreign language becomes prominent when decision making is made based on heuristics rather than analytic thinking. This fits well with a previous finding that using a foreign language leads to a reduction of heuristic biases in decision making, whereas the foreign language effect is absent in logical problems that do not involve an emotional component (Costa et al., 2014a).

In this study, positive feedback in both languages activated the reward brain networks and more importantly, the activation was higher in the foreign language than in the native language condition. It suggests that, neurophysiologically, the emotion salience of gambling outcomes, specifically, the positive feelings, was amplified more in a foreign than in a native tongue. This finding contradicts the emotion-reducing hypothesis of the foreign language effect that emotion reactions are smaller in a foreign language than in a native tongue context (Costa et al., 2014a; Keysar et al., 2012). However, it is consistent with the positive bias hypothesis that positive emotions are enhanced in the foreign language condition (Caldwell-Harris, 2015; Sheikh and Titone, 2016). Decreased emotionality in a foreign language is not invariably found (Ayiegi-Dinn and Caldwell-Harris, 2009; Caldwell-Harris et al., 2011; Harris, 2004; Schrauf and Rubin, 2007). Besides, studies on the mediation role of emotion on foreign language effect do not support the emotion-reducing hypothesis (Chan et al., 2016; Geipel, Hadjichristidis, & Surian, 2015b; Hadjichristidis et al., 2015; Morawetz, Oganian, Schlickeiser, Jacobs, & Heekeren, 2017). In contrast, previous research has demonstrated improved positive affect in foreign language condition (Caldwell-Harris et al., 2011; Hadjichristidis et al., 2015). One possibility is that learning and using a foreign language is usually in a friendly context. Negative words in a foreign tongue have few chances for emotional grounding (Sheikh and Titone, 2016). Therefore, using a foreign language may produce a positive bias. Here, the results of our study support the view that foreign language may increase the neural responses to rewards.

Subjects showed overall increased gambling in response to losses than to gains in both languages. Using neutral feedback as the referent, the foreign language feedback resulted in increased gambling in response to losses but no such change was found for losses in the native language. The native language feedback resulted in reduced gambling in response to gains but no such changes was found for wins in the foreign language. One possibility is that the baseline referents (i.e., gambling rates in neutral feedback condition) in the two language conditions were different. Comprehending a foreign language may be cognitively taxing, which may lead to more deliberative thinking (Alter et al., 2007) and less risk taking even when feedbacks are neutral (Chandler and Pronin, 2012).

Regression analysis showed that differences in brain activation to positive vs. negative feedback between two languages, predicted the cross-language difference in the use of GF-like strategy. Specially, participants with enhanced right amygdala and vmPFC responses to gains vs. losses in foreign relative to native tongue were less likely to fall into GF-like bias in foreign compared with native language context. This result suggests a negative correlation between affective decision-making and the use of GF-like strategy, which is in accordance with previous findings. For instance, brain areas involved in affective decision-making (i.e., vmPFC, amygdala) are found to be negatively correlated with the GF-like patterns (Northoff et al., 2006; Xue et al., 2011). Besides, patients with damage to emotion-related brain areas (e.g., amygdala, vmPFC, insula) showed increased risky behaviors after a series of losses (Shiv et al., 2005). These findings suggest that the affective mechanism is important for overcoming the GF or GF-like bias. Here, we observed enhanced vmPFC and amygdala activation that was associated with less GF-like biases in a foreign language context. Stronger affective decision-making triggered by a foreign tongue may keep people away from the GF-like biases when using a foreign language to present gambling outcomes.

Using PPI analysis, we found that cross-language difference in feedback-dependent amygdala-putamen/posterior insula functional connectivity was correlated negatively with the cross-language difference in the use of GF-like strategy. That is, stronger amygdala-putamen/posterior insula connectivity was associated with smaller GF-like bias in a foreign language than in native language context. Interactions between striatum and amygdala are of particular interest in reward-guided behavior. It is proposed that enhanced amygdala-striatum may contribute to poorer cognitive control and impulsive decision making, as gamblers showed an increase in functional coupling between striatum and amygdala when compared with controls (Peters et al., 2013). Insula is implicated in interoceptive awareness, urge processing, and risky decision making (Craig, 2009; Droutman et al., 2015; Naqvi and Bechara, 2010). It has been suggested that insula plays a key role in integrating interoceptive responses associated with prior experiences and its activity during decision making signals the urge for taking a risk (Xue et al., 2010). One possibility is that winning a gamble in foreign language context increased arousal, which is perceived as a feeling of urge to take a risk in the subsequent trial. Amygdala and insula have been shown to be highly interconnected anatomically (Mufson et al., 1981) and functionally (Moraga-Amaro and Stehberg, 2012). The co-activation or connectivity of the two regions has been observed in many studies involving emotion processing (Bebko et al., 2015; Kober et al., 2008; Perlman et al., 2012; Stein, 2007). Our PPI results might reflect that differences in GF-like bias between languages involves changes in bottom-up affective decision-making rather than top-down controlled process. This distinction refers to whether the mechanisms driving the foreign language effect are rooted in quick, intuitive processes or rather in deliberative, cognitive processes.

The current pattern of results suggests that using a foreign language may increase emotion reactivity, especially the positive emotions. Participants who showed stronger neural response to winning outcomes in a foreign tongue were less likely to fall into the GF-like bias in the foreign language context. It is possible that affective decision-making contributes to avoiding the GF-like bias by inhibiting deliberation. Our findings contribute to our understanding of the foreign language effect by illustrating how foreign language impacts the neural responses to feedbacks in decision making.

Declarations of interest: None.

Reference

Abdellaoui, M., Bleichrodt, H., Paraschiv, C., 2007. Loss aversion under prospect theory: A parameter-free measurement. Manage. Sci. 53, 1659–1674. https://doi.org/10.1287/mnsc.1070.0711

Alter, A.L., Oppenheimer, D.M., Epley, N., Eyre, R.N., 2007. Overcoming intuition: Metacognitive difficulty activates analytic reasoning. J. Exp. Psychol. Gen. 136, 569–576. https://doi.org/10.1037/0096-3445.136.4.569

Ayiegi-Dinn, A., Caldwell-Harris, C.L., 2009. Emotion-memory effects in bilingual speakers: A levels-of-processing approach. Bilingualism 12, 291–303. https://doi.org/10.1017/S1366728909990125

Ayton, P., Fischer, I., 2004. The hot hand fallacy and the gambler's fallacy: Two faces of subjective randomness? Mem. Cognit. 32, 1369–1378. https://doi.org/10.3758/BF03206327

Badgaiyan, R.D., 2010. Dopamine is released in the striatum during human emotional processing. Neuroreport 21, 1172–1176. https://doi.org/10.1097/WNR.0b013e3283410955

Bebko, G., Bertocci, M., Chase, H., Dwojak, A., Bonar, L., Almeida, J., Perlman, S.B., Versace, A., Schirda, C., Travis, M., Gill, M.K., Demeter, C., Diwadkar, V., Sunshine, J., Holland, S., Kowatch, R., Birmaher, B., Axelson, D., Horwitz, S., Frazier, T., Arnold, L.E., Fristad, M., Youngstrom, E., Findling, R., Phillips, M.L., 2015. Decreased amygdala–insula resting state connectivity in behaviorally and emotionally dysregulated youth. Psychiatry Res. Neuroimaging 231, 77–86. https://doi.org/10.1016/j.pscychresns.2014.10.015

Bialystok, E., Craik, F.I.M., Luk, G., 2012. Bilingualism: Consequences for mind and brain. Trends Cogn. Sci. https://doi.org/10.1016/j.tics.2012.03.001

Brevers, D., He, Q., Xue, G., Bechara, A., 2017. Neural correlates of the impact of prior outcomes on subsequent monetary decision-making in frequent poker players. Biol. Psychol. 124, 30–38. https://doi.org/10.1016/j.biopsycho.2017.01.009

Caldwell-Harris, C.L., 2015. Emotionality Differences Between a Native and Foreign Language: Implications for Everyday Life. Curr. Dir. Psychol. Sci. 24, 214–219. https://doi.org/10.1177/0963721414566268

Caldwell-Harris, C.L., Tong, J., Lung, W., Poo, S., 2011. Physiological reactivity to emotional phrases in Mandarin-English bilinguals. Int. J. Biling. 15, 329–352. https://doi.org/10.1177/1367006910379262

Campbell-Meiklejohn, D.K., Woolrich, M.W., Passingham, R.E., Rogers, R.D., 2008. Knowing When to Stop: The Brain Mechanisms of Chasing Losses. Biol. Psychiatry 63, 293–300. https://doi.org/10.1016/j.biopsych.2007.05.014

Chan, Y.-L., Gu, X., Ng, J.C.-K., Tse, C.-S., 2016. Effects of dilemma type, language, and emotion arousal on utilitarian vs deontological choice to moral dilemmas in Chinese-English bilinguals. Asian J. Soc. Psychol. 19, 55–65. https://doi.org/10.1111/ajsp.12123
Chandler, J.J., Pronin, E., 2012. Fast Thought Speed Induces Risk Taking. Psychol. Sci. 23, 370–374. https://doi.org/10.1177/0956797611431464
Conrad, M., Recio, G., Jacobs, A.M., 2011. The Time Course of Emotion Effects in First and Second Language Processing: A Cross Cultural ERP Study with German?Spanish Bilinguals. Front. Psychol. 2. https://doi.org/10.3389/fpsyg.2011.00351
Corey, J.D., Hayakawa, S., Foucart, A., Aparici, M., Botella, J., Costa, A., Keysar, B., 2017. Our moral choices are foreign to us. J. Exp. Psychol. Learn. Mem. Cogn. 43, 1109–1128. https://doi.org/10.1037/xlm0000356
Costa, A., Foucart, A., Arnon, I., Aparici, M., Apesteguia, J., 2014a. “Piensa” twice: On the foreign language effect in decision making. Cognition 130, 236–254. https://doi.org/10.1016/j.cognition.2013.11.010
Costa, A., Foucart, A., Hayakawa, S., Aparici, M., Apesteguia, J., Heafner, J., Keysar, B., 2014b. Your morals depend on language. PLoS One 9. https://doi.org/10.1371/journal.pone.0094842
Costa, A., Vives, M., Corey, J.D., 2017. On Language Processing Shaping Decision Making. Curr. Dir. Psychol. Sci. 26, 146–151. https://doi.org/10.1177/0963721416680263
Craig, A.D., 2009. How do you feel — now? The anterior insula and human awareness. Nat. Rev. Neurosci. 10, 59–70. https://doi.org/10.1038/nrn2555
Dewaele, J.-M., 2004. The Emotional Force of Swearwords and Taboo Words in the Speech of Multilinguals. J. Multiling. Multicult. Dev. 25, 204–222. https://doi.org/10.1080/01434630408666529
Dong, G., Lin, X., Zhou, H., Du, X., 2014. Decision-making after continuous wins or losses in a randomized guessing task: implications for how the prior selection results affect subsequent decision-making. Behav. Brain Funct. 10, 11. https://doi.org/10.1186/1744-9081-10-11
Droutman, V., Bechara, A., Read, S.J., 2015. Roles of the Different Sub-Regions of the Insular Cortex in Various Phases of the Decision-Making Process. Front. Behav. Neurosci. 9. https://doi.org/10.3389/fnbeh.2015.00309
François Grosjean, 2010. Bilingual: Life and reality. Cambridge, MA: Harvard University Press.
Friston, K.., Buechel, C., Fink, G.., Morris, J., Rolls, E., Dolan, R.., 1997. Psychophysiological and Modulatory Interactions in Neuroimaging. Neuroimage 6, 218–229. https://doi.org/10.1006/nimg.1997.0291
Gao, S., Zika, O., Rogers, R.D., Thierry, G., 2015. Second Language Feedback Abolishes the “Hot Hand” Effect during Even-Probability Gambling. J. Neurosci. 35, 5983–5989.

https://doi.org/10.1523/JNEUROSCI.3622-14.2015
Geipel, J., Hadjichristidis, C., Surian, L., 2016. Foreign language affects the contribution of intentions and outcomes to moral judgment. Cognition 154, 34–39. https://doi.org/10.1016/j.cognition.2016.05.010
Geipel, J., Hadjichristidis, C., Surian, L., 2015a. How foreign language shapes moral judgment. J. Exp. Soc. Psychol. 59, 8–17. https://doi.org/10.1016/j.jesp.2015.02.001
Geipel, J., Hadjichristidis, C., Surian, L., 2015b. The Foreign Language Effect on Moral Judgment: The Role of Emotions and Norms. PLoS One 10, e0131529. https://doi.org/10.1371/journal.pone.0131529
George, J.M., Dane, E., 2016. Affect, emotion, and decision making. Organ. Behav. Hum. Decis. Process. 136, 47–55. https://doi.org/10.1016/j.obhdp.2016.06.004
Gitelman, D.R., Penny, W.D., Ashburner, J., Friston, K.J., 2003. Modeling regional and psychophysiologic interactions in fMRI: the importance of hemodynamic deconvolution. Neuroimage 19, 200–207. https://doi.org/10.1016/S1053-8119(03)00058-2
Gu, X., Hof, P.R., Friston, K.J., Fan, J., 2013. Anterior insular cortex and emotional awareness. J. Comp. Neurol. 521, 3371–3388. https://doi.org/10.1002/cne.23368
Haber, S.N., Knutson, B., 2010. The Reward Circuit: Linking Primate Anatomy and Human Imaging. Neuropsychopharmacology 35, 4–26. https://doi.org/10.1038/npp.2009.129
Hadjichristidis, C., Geipel, J., Savadori, L., 2015. The effect of foreign language in judgments of risk and benefit: The role of affect. J. Exp. Psychol. Appl. 21, 117–129. https://doi.org/10.1037/xap0000044
Harris, C.L., 2004. Bilingual speakers in the lab: Psychophysiological measures of emotional reactivity. J. Multiling. Multicult. Dev. 25, 223–247. https://doi.org/10.1080/01434630408666530
Harris, C.L., Ayçiçeği, A., Gleason, J.B., 2003. Taboo words and reprimands elicit greater autonomic reactivity in a first language than in a second language. Appl. Psycholinguist. 24, 561–579. https://doi.org/10.1017/S0142716403000286
Hayakawa, S., Costa, A., Foucart, A., Keysar, B., 2016. Using a Foreign Language Changes Our Choices. Trends Cogn. Sci. 20, 791–793. https://doi.org/10.1016/j.tics.2016.08.004
Hayakawa, S., Tannenbaum, D., Costa, A., Corey, J.D., Keysar, B., 2017. Thinking More or Feeling Less? Explaining the Foreign-Language Effect on Moral Judgment. Psychol. Sci. 28, 1387–1397. https://doi.org/10.1177/0956797617720944
Hsu, C.-T., Jacobs, A.M., Conrad, M., 2015. Can Harry Potter still put a spell on us in a second language? An fMRI study on reading emotion-laden literature in late bilinguals. Cortex 63, 282–295. https://doi.org/10.1016/j.cortex.2014.09.002

Huang, X., Zhang, H., Chen, C., Xue, G., He, Q., 2019. The neuroanatomical basis of the Gambler's fallacy: A univariate and multivariate morphometric study. Hum. Brain Mapp. 40, 967–975. https://doi.org/10.1002/hbm.24425

Iacozza, S., Costa, A., Duñabeitia, J.A., 2017. What do your eyes reveal about your foreign language? Reading emotional sentences in a native and foreign language. PLoS One 12, e0186027. https://doi.org/10.1371/journal.pone.0186027

Ji, L.-J., McGeorge, K., Li, Y., Lee, A., Zhang, Z., 2015. Culture and gambling fallacies. Springerplus 4, 510. https://doi.org/10.1186/s40064-015-1290-2

Keysar, B., Hayakawa, S.L., An, S.G., 2012. The Foreign-Language Effect. Psychol. Sci. 23, 661–668. https://doi.org/10.1177/0956797611432178

Kober, H., Barrett, L.F., Joseph, J., Bliss-Moreau, E., Lindquist, K., Wager, T.D., 2008. Functional grouping and cortical–subcortical interactions in emotion: A meta-analysis of neuroimaging studies. Neuroimage 42, 998–1031. https://doi.org/10.1016/j.neuroimage.2008.03.059

Losecaat Vermeer, A.B., Boksem, M.A.S., Sanfey, A.G., 2014. Neural mechanisms underlying context-dependent shifts in risk preferences. Neuroimage 103, 355–363. https://doi.org/10.1016/j.neuroimage.2014.09.054

Marian, V., Shook, A., 2012. The cognitive benefits of being bilingual. Cerebrum 2012, 13.

Moore, S.C., Chater, N., 1999. The Influence of Affect on Risky Behavior : From the Lab to Real World Financial Behavior. Proc. 23rd Annu. Conf. Cogn. Sci. Soc. 822–827.

Moraga-Amaro, R., Stehberg, J., 2012. The Insular Cortex and the Amygdala: Shared Functions and Interactions, in: The Amygdala - A Discrete Multitasking Manager. InTech. https://doi.org/10.5772/48495

Muda, R., Niszczota, P., Białek, M., Conway, P., 2018. Reading dilemmas in a foreign language reduces both deontological and utilitarian response tendencies. J. Exp. Psychol. Learn. Mem. Cogn. 44, 321–326. https://doi.org/10.1037/xlm0000447

Mufson, E.J., Mesulam, M.-M., Pandya, D.N., 1981. Insular interconnections with the amygdala in the rhesus monkey. Neuroscience 6, 1231–1248. https://doi.org/10.1016/0306-4522(81)90184-6

Murray, E.A., 2007. The amygdala, reward and emotion. Trends Cogn. Sci. 11, 489–497. https://doi.org/10.1016/j.tics.2007.08.013

Naqvi, N.H., Bechara, A., 2010. The insula and drug addiction: an interoceptive view of pleasure, urges, and decision-making. Brain Struct. Funct. 214, 435–450. https://doi.org/10.1007/s00429-010-0268-7

Northoff, G., Grimm, S., Boeker, H., Schmidt, C., Bermpohl, F., Heinzel, A., Hell, D., Boesiger, P., 2006. Affective judgment and beneficial decision making: Ventromedial prefrontal activity correlates with performance in the Iowa Gambling Task. Hum. Brain Mapp. 27, 572–587. https://doi.org/10.1002/hbm.20202

O'Doherty, J., 2004. Dissociable Roles of Ventral and Dorsal Striatum in Instrumental Conditioning. Science (80-.). 304, 452–454. https://doi.org/10.1126/science.1094285

O'Reilly, J.X., Woolrich, M.W., Behrens, T.E.J., Smith, S.M., Johansen-Berg, H., 2012. Tools of the trade: psychophysiological interactions and functional connectivity. Soc. Cogn. Affect. Neurosci. 7, 604–609. https://doi.org/10.1093/scan/nss055

Pavlenko, A., 2012. Affective processing in bilingual speakers: Disembodied cognition? Int. J. Psychol. 47, 405–428. https://doi.org/10.1080/00207594.2012.743665

Perlman, G., Simmons, A.N., Wu, J., Hahn, K.S., Tapert, S.F., Max, J.E., Paulus, M.P., Brown, G.G., Frank, G.K., Campbell-Sills, L., Yang, T.T., 2012. Amygdala response and functional connectivity during emotion regulation: A study of 14 depressed adolescents. J. Affect. Disord. 139, 75–84. https://doi.org/10.1016/j.jad.2012.01.044

Peters, J., Miedl, S.F., Büchel, C., 2013. Elevated Functional Connectivity in a Striatal-Amygdala Circuit in Pathological Gamblers. PLoS One 8, e74353. https://doi.org/10.1371/journal.pone.0074353

Raylu, N., Oei, T.P., 2004. Role of culture in gambling and problem gambling. Clin. Psychol. Rev. 23, 1087–1114. https://doi.org/10.1016/j.cpr.2003.09.005

Samanez-Larkin, G.R., Hollon, N.G., Carstensen, L.L., Knutson, B., 2008. Individual Differences in Insular Sensitivity During Loss Anticipation Predict Avoidance Learning. Psychol. Sci. 19, 320–323. https://doi.org/10.1111/j.1467-9280.2008.02087.x

Schrauf, R.W., Rubin, D.C., 2007. The 'language' and 'feel' of bilingual memory: Mnemonic traces. Socioling. Stud. 5. https://doi.org/10.1558/sols.v5i1.21

Schultz, W., Dayan, P., Montague, P.R., 1997. A Neural Substrate of Prediction and Reward. Science (80-.). 275, 1593–1599. https://doi.org/10.1126/science.275.5306.1593

Sheikh, N.A., Titone, D., 2016. The embodiment of emotional words in a second language: An eye-movement study. Cogn. Emot. 30, 488–500. https://doi.org/10.1080/02699931.2015.1018144

Shiv, B., Loewenstein, G., Bechara, A., Damasio, H., Damasio, A.R., 2005. Investment Behavior and the Negative Side of Emotion. Psychol. Sci. 16, 435–440. https://doi.org/10.1111/j.0956-7976.2005.01553.x

Stanovich, K.E., West, R.F., Hertwig, R., 2000. Individual differences in reasoning: {Implications} for the rationality debate?-{Open} {Peer} {Commentary}-{The} questionable utility of cognitive ability in explaining cognitive illusions 645–726.

Stein, M., 2007. Increased Amygdala and Insula Activation During Emotion Processing in Anxiety-Prone Subjects. Am. J. Psychiatry 164, 318. https://doi.org/10.1176/appi.ajp.164.2.318

Tom, S.M., Fox, C.R., Trepel, C., Poldrack, R.A., 2007. The neural basis of loss aversion in decision-making under risk. Science (80-.). 315, 515–518. https://doi.org/10.1126/science.1134239

Tversky, A., Kahneman, D., 2016. Advances in Prospect Theory: Cumulative Representation of Uncertainty, in: Readings in Formal Epistemology. Springer International Publishing, Cham, pp. 493–519. https://doi.org/10.1007/978-3-319-20451-2_24

Tversky, A., Kahneman, D., 1992. Advances in prospect theory: Cumulative representation of uncertainty. J. Risk Uncertain. 5, 297–323. https://doi.org/10.1007/BF00122574

Tversky, A., Kahneman, D., 1974. Judgment under Uncertainty: Heuristics and Biases. Science (80-.). 185, 1124–1131. https://doi.org/10.1126/science.185.4157.1124

Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., Mazoyer, B., Joliot, M., 2002. Automated Anatomical Labeling of Activations in SPM Using a Macroscopic Anatomical Parcellation of the MNI MRI Single-Subject Brain. Neuroimage 15, 273–289. https://doi.org/10.1006/nimg.2001.0978

van Hugten, J., van Witteloostuijn, A., 2018. The foreign language effect on the self-serving bias: A field experiment in the high school classroom. PLoS One 13, e0192143. https://doi.org/10.1371/journal.pone.0192143

Warriner, A.B., Kuperman, V., Brysbaert, M., 2013. Norms of valence, arousal, and dominance for 13,915 English lemmas. Behav. Res. Methods 45, 1191–1207. https://doi.org/10.3758/s13428-012-0314-x

Winecoff, A., Clithero, J.A., Carter, R.M., Bergman, S.R., Wang, L., Huettel, S.A., 2013. Ventromedial Prefrontal Cortex Encodes Emotional Value. J. Neurosci. 33, 11032–11039. https://doi.org/10.1523/JNEUROSCI.4317-12.2013

Wu, Y.J., Thierry, G., 2012. How Reading in a Second Language Protects Your Heart. J. Neurosci. 32, 6485–6489. https://doi.org/10.1523/jneurosci.6119-11.2012

Xue, G., He, Q., Lei, X., Chen, C., Liu, Y., Chen, C., Lu, Z.-L., Dong, Q., Bechara, A., 2012a. The Gambler's Fallacy Is Associated with Weak Affective Decision Making but Strong Cognitive Ability. PLoS One 7, e47019. https://doi.org/10.1371/journal.pone.0047019

Xue, G., Juan, C.-H., Chang, C.-F., Lu, Z.-L., Dong, Q., 2012b. Lateral prefrontal cortex contributes to maladaptive decisions. Proc. Natl. Acad. Sci. 109, 4401–4406. https://doi.org/10.1073/pnas.1111927109

Xue, G., Lu, Z., Levin, I.P., Bechara, A., 2011. An fMRI study of risk-taking following wins and losses: Implications for the gambler's fallacy. Hum. Brain Mapp. 32, 271–281. https://doi.org/10.1002/hbm.21015

Xue, G., Lu, Z., Levin, I.P., Bechara, A., 2010. The impact of prior risk experiences on subsequent risky decision-making: The role of the insula. Neuroimage 50, 709–716.

https://doi.org/10.1016/j.neuroimage.2009.12.097

Figure 1. Experimental paradigm. First, the gamble options "play" and "leave" were presented. Participants determine whether they wanted to play or not each gamble within 4 s. The selected option was highlighted for the rest of 4 s. After that, feedback in either foreign language (English) or native language (Chinese) was provided for 2 s in the form of a printed word followed by the corresponding numerical outcome, displayed for 1 s.

Figure 2. (A) Bilateral caudate and bilateral amygdala were significantly more activated for positive vs. negative feedback in the English condition than in the Chinese condition. (B) Scatterplot of correlation between neural d-GF (cross-language (English-Chinese) difference in positive vs. negative feedback contrast) and behavioral d-GF (beta coefficient representing the cross-language difference (Chinese-English) in risky choices after negative vs. positive feedback) in the right amygdala and vmPFC. (C) Scatterplot of correlation between behavioral d-GF and cross-language (English-Chinese) difference in feedback-dependent (positive vs. negative feedback) functional connectivity between the right amygdala and right putamen/right posterior insula. Regression line and *P* value were computed with the use of whole-brain regression after removing one extreme data point from the analysis. ** indicating $p < 0.01$, *** indicating $p < 0.001$.

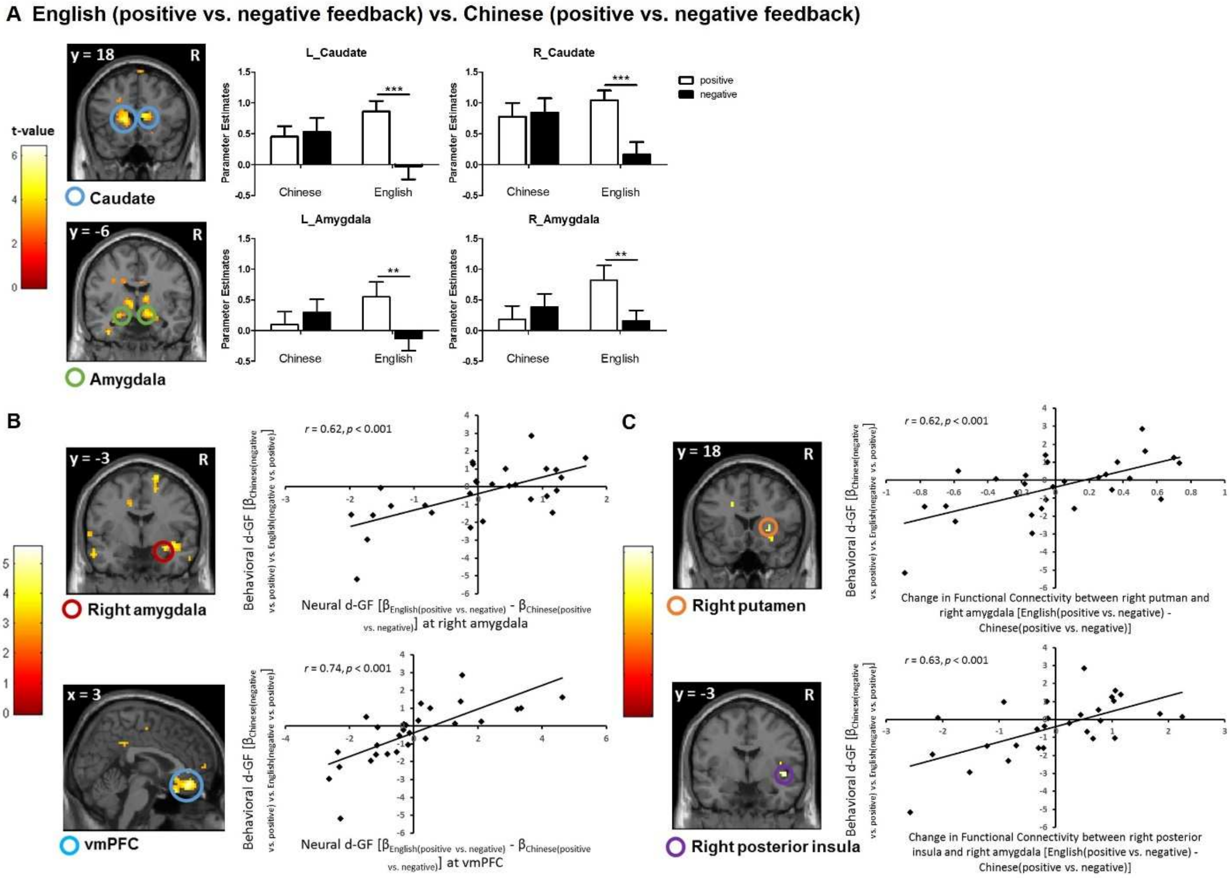

Table 1. Feedback words used in the gambling task

Feedback emotional valence	English	Chinese
Positive	Good	很好
	Cool	真行
	Great	超赞
	Excellent	太棒了
	Wonderful	了不起
Negative	Bad	糟糕
	Sorry	遗憾
	Sad	悲催
	Damn	真可恶
	Terrible	太惨了
Neutral	Leave	不赌

Table 2. Brain activations elicited in the positive vs. negative feedback contrast in both Chinese and English conditions (Cluster-forming threshold at $p < 0.005$, cluster-wise corrected, pFWE < 0.05. Asterisk indicates pFWE < 0.05 after small volumn correction).

Regions	Hemisphere	Cluster size (voxels)	Peak Coordinates MNI (x, y, z)	Peak intensity (T value)
Positive > Negative				
Chinese				
Ventral striatum	L/R	28	12 6 -15	5.08*
Caudate	L/R	20	12 9 -12	4.79*
Putamen	L/R	5	15 9 -9	4.18*
Amygdala	L	2	-18 0 -21	3.16*
vmPFC	L/R	24	6 39 -12	3.89*
ACC	L	258	-9 42 0	4.54
IPL	R	462	57 -45 51	3.79
English				
Ventral striatum	L/R	29	12 6 -6	4.69*
Caudate	L/R	136	12 15 12	5.58*
Putamen	L/R	69	-15 9 -3	4.78*
Amygdala	L/R	40	-18 0 -12	4.67*
vmPFC	L/R	34	3 36 -9	4.10*
ACC	L/R	5757	24 27 9	6.00
Lingual Gyrus	L/R	2073	-18 -90 -9	6.22
MCC/PCC	L/R	219	3 -45 36	4.02
English>Chinese				
Caudate	L/R	48	-15 21 9	6.42*
Amygdala	L/R	12	21 -6 -12	4.61*
Sub-Gyral	L	264	-36 -39 -3	5.22
Negative > Positive				
none				

IPL, inferior parietal lobule. vmPFC, ventral medial prefrontal cortex. ACC, anterior cingulate cortex. MCC, middle cingulate cortex. PCC, posterior cingulate cortex.

bilateral caudate and amygdala gain signals were exaggerated by foreign language

foreign language effect was associated with activation in the right amygdala and ventromedial prefrontal cortex

foreign language effect was associated with functional connectivity between right amygdala and right putamen/right posterior insula

R. Yu developed the study concept. L. Zhen analyzed and interpreted the data under the supervision of R. Yu. L. Zhen drafted the manuscript, and R. Yu and D. Mobbs provided critical revisions. All authors approved the final version of the manuscript for submission.